months—I feel obliged to share with you my personal definition. It goes something like this. Retirement is the final career for you *and* your spouse, if you have one, since no one retires alone if one is married. When your last graduate student has been dropped from the family payroll; when you no longer leap out of bed at the crack of dawn with a song in your heart in eager anticipation of beating the freeway gridlock or making early morning rounds before spending another day in the office; when your wise and wily financial adviser smilingly gives you the green light: Yes, notwithstanding unforeseen fluctuations in the market, you have enough squirreled away to live for the next 20 or 30 years almost in the manner to which you have become accustomed; and—perhaps most important—you and your spouse really believe that you will have fun living eyeball-to-eyeball 24 hours a day, seven days a week, forevermore. If all the responses are positive, you are ready to retire—*if you have a plan.* This is your final career. And, make no mistake, it is a career, and it will require every bit as much planning (perhaps more) than any other of your careers.

I may be a novice retiree, but I am a veteran observer of unsuccessful retirements. One was of a tough, vigorous 62-year-old four-star general who commanded a corps in combat and an army in peacetime. He could not wait to "hang it up and devote my life to golf, hunting, fishing, and reading all the books I never had time for." You know the story. After six months he was bored out of his gourd; at 12 months he was severely depressed. Within two years he was dead. You can change the characters and the scenery, but the story is all too familiar.

Virshup and Coombs present a much more optimistic outlook: "Most physicians enjoy the freedom and activities of retirement . . . . Fears of boredom and deterioration are unfounded." This has been my experience as well, but there are a few fascinating facts that emerge from their study. Only 27 responded that they had prepared "extremely well" for retirement; 52 said "fairly well," 13 "so-so," and 8 poorly. To me, this means that 73 were asking for trouble. The authors do not define "prepared," and that to me is the key. Let me explain.

As I alluded to earlier, somewhat facetiously, there are several prime ingredients to a "successful" retirement. Good health is cardinal, and it is a bit more than the blessing of good genes and good luck. At least 30 or 40 years of conscious attention to the controllables, such as rational dietary discipline, reasonable regular exercise, avoidance of cigarettes and excess alcohol, insightful management of stressors, and buckling up the seat belts, pay off. It is a tragedy to arrive at retirement in a state of physical disrepair—especially if it could have been prevented—and find your options severely limited.

Next comes financial security. One would assume that this should not be a problem for physicians, but all too often even my wisest colleagues underestimate what will be required to maintain their standard of living. Early planning with a "wise and wily" financial adviser is mandatory.

The next facet of planning comes with a realistic calculation of how to balance intellectual, physical, cultural, and social activities. (This is where my unfortunate general ran aground). For each person, this balance will be intimately personal, and this is where many hours of long, serious conversation with your spouse are critical—again, many years in advance of that great day.

Despite how much a person loves being a physician (or a mathematician or a carpenter), there will come a time to step aside. I am always saddened by the vision of emptiness I perceive when a friend says, "I love my work so much that I plan to die in harness." How narrow and impoverished is a life that has not tasted some of the wonderful things that lie beyond any "work" and has not been tempted to savor them a little more. Admittedly, sometimes the best-laid plans do not ensure success in retirement. Ill health is always an evil joker in the deck. So is a sudden unplanned financial setback ("Janice just called from Swarthmore; she has changed her mind and now wants to go to medical school. And Ted has finally decided to open a men's clothing store!") or *triste dictu*—one morning your spouse of 30 years looks you in the eye and says, "I think we need to give each other a little more space, now that you're home all the time." But the ultimate catastrophe is to wake up each morning and lie awake contemplating the day without joy. Then you must beware the treacherous handmaiden, melancholia.

As in any sound experiment, the only way one can hope to eliminate the uncontrolled variables is to devise a thoughtful protocol—your balanced retirement plan. Each of us must derive the all-important balance that suits a "retirement team." My wife and I retired to a mountaintop in northern New Mexico. We sought serenity, physical beauty, and solitude—after what seemed a lifetime in Megalopolis. The rugged environment demands a great deal of physical activity—cutting and hand-splitting firewood, shoveling and plowing snow in winter, snowshoeing and cross-country skiing, and many other outdoor activities. Our intellectual activities are related to some professional consulting and committee work (not enough to intrude) and pro bono work (it is amazing how desirable you become to national organizations when they know you have the time—but one can pick and choose).

I think we have achieved reasonable balance in our new career. So Virshup and Coombs are right: you will enjoy having the time to sniff the flowers—if you plan ahead.

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Endovascular Neurosurgery—The Marriage of Imaging and Intravascular Therapy in the Decade of the Brain

Disease is from of old and nothing about it has changed. It is we who change as we learn to recognize what was formerly imperceptible.

JEAN-MARTIN CHARCOT
Lectures on the Localization of Cerebral and Spinal Diseases, 1883

INTERVENTIONAL NEURORADIOLOGY, or endovascular neurosurgery, is emerging as a new and recognized subspecialty that bridges the fields of neuroradiology, neurosurgery, vascular surgery, otolaryngology, and neurology. In the late 1970s and early 1980s, this field was sparsely populated by a handful of unconventional physicians in neuroradiology who undertook unconventional treatment of neurovascular disorders that were thought to be untreatable. These included vascular disorders with nearly 100% mortality, such as vein of Galen malformations in the newborn, unresectable large arteriovenous malformations, and giant intracavernous aneurysms that were not surgically accessible.

These unconventional treatment modalities delivered such materials as silicone spheres, lyophilized human dura, tiny sponges, detachable balloons, and "crazy glue" [cyanoacrylate] to close vessels through intravascular catheters for an increasing spectrum of vascular diseases. The early development of this field was limited by primitive imaging devices, a lack of industry commitment to developing delivery systems to the brain from an endovascular approach (small microcatheters and guide wires), and a lack of adequate resources and funding for evaluating embolic materials implanted in the brain's blood vessels.

The early pioneers in interventional neuroradiology had maverick qualities, however, "to go where no one has gone before" (despite potential malpractice) and to "use what no one has dared to use" in approaches to neurologic diseases. As a result, this field is just now being recognized as one of the emerging specialties of minimally invasive surgery. This is an extremely timely and appropriate evolution for this specialty in the "decade of the brain."

New Technology

Elsewhere in this issue, Barnwell gives an excellent overview of how far this field has evolved in a relatively short period of time.[1] Several factors have contributed to the progress of the past decade:

- Enormous strides have been made in medical imaging by the commitment of major industrial firms to medical technology, including such household names as General Electric, Phillips Corporation, and Toshiba. The development of computed tomography, intravascular ultrasonography, magnetic resonance imaging, and high-resolution digital subtraction angiography, fostered by the medical divisions of these companies, has made the noninvasive and minimally invasive testing and diagnosis of complex medical disorders fairly routine and efficacious.
- Advances in medical technology in microcatheters, steerable guide wires, angioplasty devices, stents, and embolic materials by companies such as Boston Scientific, Cook, Cordis, Target Therapeutics, Pfizer, and Johnson & Johnson have now made it technically feasible to achieve safe and accurate access to almost all territories of the body, including the brain.

Nowhere has this combination of medical imaging and technology had greater influence in diagnosis and therapy than in the brain. In the past we had to rely on inference from clinical testing, indirect testing by electroencephalography, obtrusive observations by pneumoencephalography, and cerebral arteriography by direct carotid puncture. The presence of brain tumors or intracerebral hemorrhages could not actually be visualized but had to be inferred from associated compression of nearby blood vessels and ventricles.

Now we can simply request magnetic resonance imaging or a computed tomographic scan of the brain to rule out structural pathology for the complaints of headaches, seizures, head trauma, or strange and aberrant behavior. Possibly in the near future these procedures will be used for routine screening for strokes—currently the third leading cause of death in the United States. We are only now beginning to realize the important effects this is having on current medical diagnosis and therapy.

Intracranial Aneurysm Therapy

It is estimated from autopsy studies that 1.5% to 8.0% of the population harbors at least one intracranial aneurysm, and 20% of these people have more than one.[2,3] If we assume a 2% incidence for an aneurysm, there are currently 4.8 million potentially treatable patients in the United States. Currently 60,000 to 80,000 cases of acute subarachnoid hemorrhage occur per year in North America, most of which are caused by an intracranial aneurysm. A ruptured intracranial aneurysm causes death in 50% of patients within the first 24 to 48 hours. In a third of those who survive this period of time vasospasm develops, often leading to subsequent stroke or death. The remaining survivors who come to surgery will be normal or near normal in only 50% of cases because of the residual effect of the initial hemorrhage.[4,5]

What if we had the ability to screen patients older than 40 to 50 years for an intracranial aneurysm using magnetic resonance imaging? They could then be treated to prevent the risk of a catastrophic hemorrhage.[6,7] The implications are enormous. We must consider the quality-of-life issue versus the financial effects. First of all, the costs to treat patients under general anesthesia with craniotomy, surgical clipping, and a recovery time of six to eight weeks before returning to work are considerable. Interventional neuroradiologic therapy for such patients is much simpler. After the diagnosis is made by noninvasive testing, patients are admitted to the hospital on the day of the interventional procedure. An arteriogram is done under local anesthesia to confirm where the aneurysm is located. A microcatheter is then guided through the diagnostic catheter and placed directly into the aneurysm under fluoroscopic guidance. An embolic agent is then carefully introduced into the aneurysm to occlude it, usually taking 30 minutes to 2 hours. After observation overnight in the hospital, the patient goes home the next day and can return to work in three to five days after the procedure.[8-10] This results in a savings of about a fifth of the medical cost and a tenth of the time lost from work. The savings in costs and productive work time alone should justify this type of continued research for the safety and efficacy of intracranial aneurysm therapy.

Surgical clipping of aneurysms is now the standard of practice in this country. Endovascular therapy is, however, the standard of practice in Russia at the Kiev Neurosurgical Institute, where all patients with an intracranial aneurysm are first treated by detachable balloons. Only if that treatment fails do patients undergo neurosurgical clipping.[11,12] Similar approaches to therapy are now being advocated by some French neuroradiologic specialists.[13]

Will this type of minimally invasive therapy become the standard of treatment for the rest of the medical community? Only time and further innovations in this technology can tell. Current national and international cooperative studies are evaluating endovascular therapy for intracranial aneurysms using the electrolytic detachable microcoil in surgically difficult aneurysms.[14] If these results are favorable, the next logical step will be to evaluate this treatment for certain types of aneurysms as an adjunct or in place of standard surgical treatment.

Cerebral Angioplasty

The safety and efficacy of cerebral percutaneous transluminal angioplasty for atherosclerotic disease are also being examined. Angioplasty has been performed in selected cases since the early 1980s in the carotid, vertebral, and intracranial circulation to alleviate cerebral ischemia and stroke.[15,16]

Currently 60,000 to 100,000 patients annually undergo carotid endarterectomy for cerebral atherosclerosis in North America. This therapy has now been validated as efficacious in relieving the risk of stroke in patients with symptomatic stenosis of greater than 70%. The ability of interventional neuroradiologists to treat this disease by balloon angioplasty techniques, similar to those used by cardiologists and vascular radiologists who treat the coronary, renal, iliac, and other peripheral vessels of the body is now being examined.[17] A group approved by the Society of Cardiovascular and Interventional Radiology and the Joint Section on Cerebrovascular Surgery has established a national registry at 15 medical centers in the United States to evaluate this potentially large group of patients.

Head Trauma

The precedent of interventional therapy for treating complex cerebrovascular diseases has already been established in the area of head trauma. Before 1980, the surgical therapy for traumatic carotid-cavernous sinus fistulas was a craniotomy and occlusion of the cavernous sinus or ligation of the extracranial and intracranial internal carotid artery. The surgical complication rate was greater than 30%, and often cure of the fistula was not achieved.

Since 1980 the cure rate by interventional neuroradiology has approached 100%, and the complication rate is less than 4%. It is now becoming the standard of practice that patients with a traumatic fistula involving the carotid or vertebral artery are best managed by interventional techniques; only if these techniques fail should a surgical procedure be considered.[18]

Advantages of Endovascular Surgery

Endovascular therapy has many advantages in the treatment of a wide variety of complex cerebrovascular disorders, including arteriovenous malformations, intracranial aneurysms, traumatic vascular diseases, vasospasm, embolic stroke, and highly vascular tumors. Because the procedures are performed under local anesthesia, the awake patients can undergo constant neurologic monitoring of their clinical condition. As a major brain artery is treated, testing can be done initially to ensure tolerance to therapy. In patients undergoing craniotomy under general anesthesia, this is usually not possible. In addition, blood loss by interventional therapy is minimal; therefore, blood transfusions are unnecessary, even when treating highly vascular malformations or tumors. The stay in a hospital is kept to a minimum, with most patients leaving within 24 to 48 hours following the procedure, with minimal time lost from work.[19,20]

Conclusion

Minimally invasive surgery has had a major effect on many conditions, including endoscopy and lithotripsy for gallstones and kidney stones, angioplasty and stenting for coronary artery and visceral atherosclerosis, and transjugular intrahepatic portosystemic shunts for end-stage liver disease associated with variceal hemorrhage. Industry will continue to fund the research and development of this area as the next generation of imaging and medical devices is produced. In the future it is possible that endovascular surgery will be performed using real-time magnetic resonance imaging and intravascular ultrasonography without the need for radiographic fluoroscopy.

Government needs to recognize that it should not overly restrict the medical device industry by rules, regulations, and bureaucratic processes. The federal government may facilitate advances in device development by establishing another mechanism through the regulatory process to decrease the enormous costs and liability associated with new and innovative technology.

The implications for improvement in the quality of life for persons with cerebrovascular disease are enormous. Health care costs should also be substantially reduced by interventional techniques if comparable or improved morbidity statistics can continue to be achieved.

Future breakthroughs in minimally invasive therapy will rapidly change the way medicine is currently being practiced as these techniques continue to evolve for all parts of the body including the brain.

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